Science and Technology Facilities Council

Central Laser Facility

central laser facility

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From Square to Circle using a SQUIRCLE

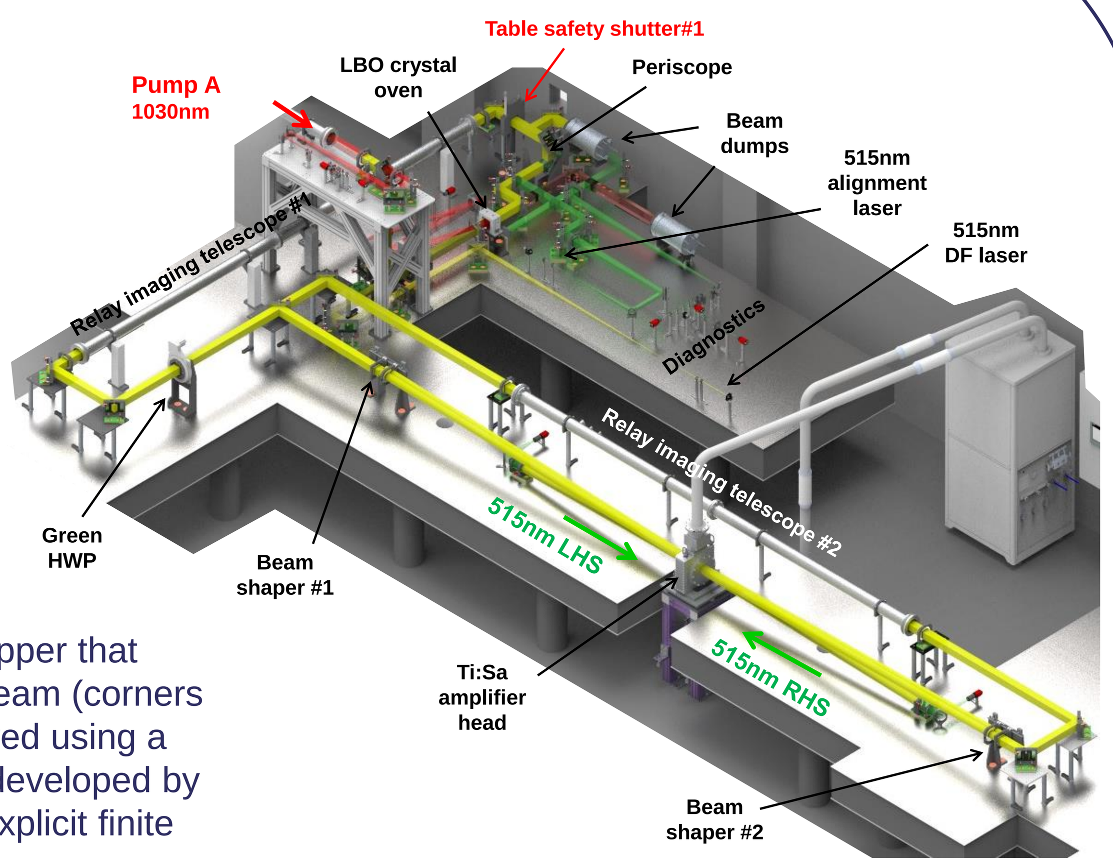
Introduction

Why do we need to reshape the beam?

The EPAC Front End produces a 52 mm circular super-Gaussian seed beam, but the EPAC Pump Laser produces a 65 mm square super-Gaussian after green conversion. The green beam is reshaped to a circular super-Gaussian to match the shape of the seed to ensure efficient amplification in the EPAC Ti:Sa amplifier.

What is a SQUIRCLE beamshaper?

A SQUIRCLE is a custom designed field-mapper that redirects energy from undesired parts of a beam (corners of square) to the chosen area. This is achieved using a custom mapping algorithm which has been developed by solving the Monge-Ampère equation using explicit finite differences.



Layout of the green pump beam path for the EPAC Ti:Sa Amplifier

These devices are manufactured by generating a micro-structured shaped surface on a fused silica substrate using a CO_2 laser in a two stage process:

- *Stage 1: Material removal / shaping*
- *Stage 2: Surface melting & smoothing*

PowerPhotonic
Enhancing Beam Performance

Photograph of prototype SQUIRCLE beamshaper

Prototype testing

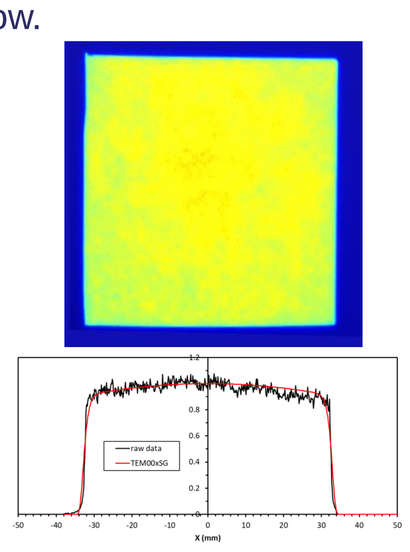
A prototype EPAC-scale SQUIRCLE has been made by PowerPhotonic and characterised at the CLF to investigate its properties and determine suitability for use in EPAC.

Preliminary tests:

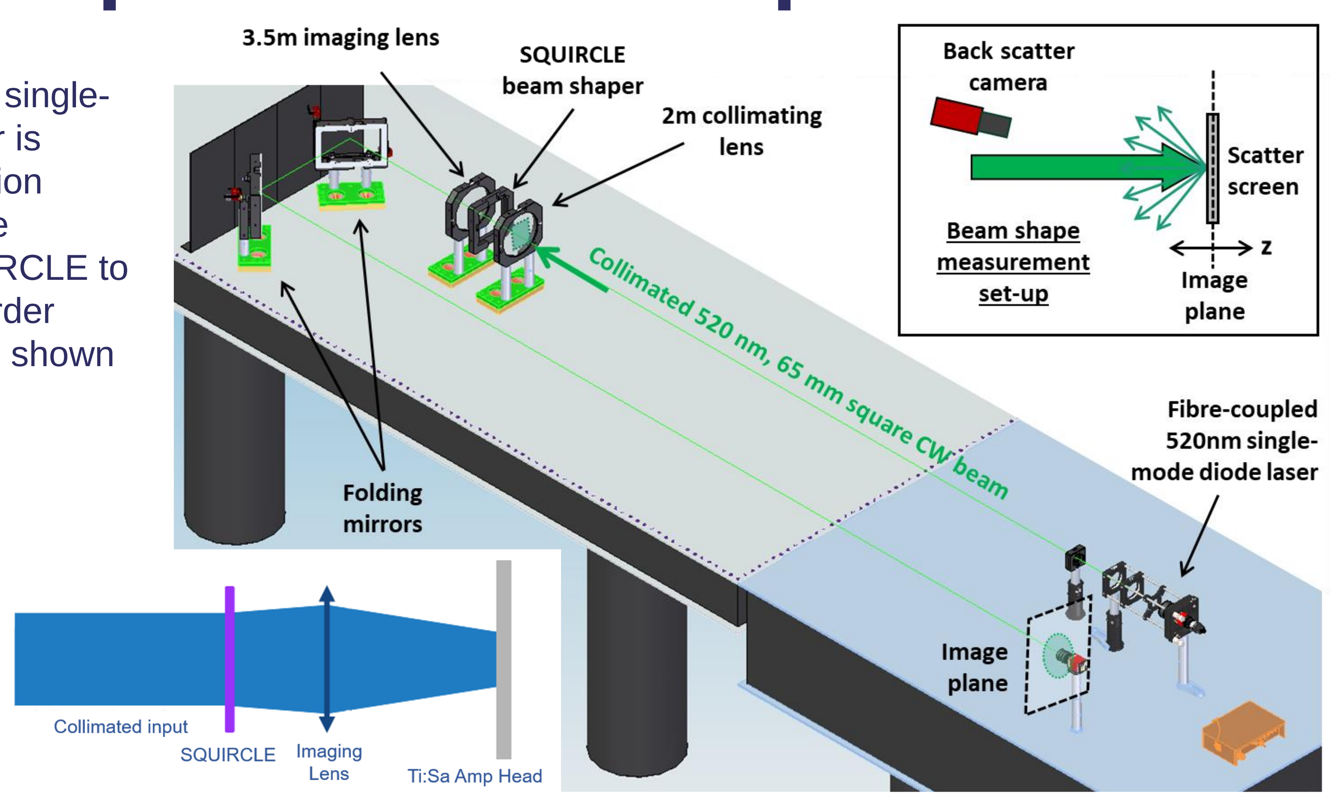
1. *Confirm size & shape of beam profile at the image plane*
2. *Investigate the uniformity & fluence profile of the beam – does SQUIRCLE imprint a pattern on beam?*
3. *Measure the efficiency of the device to confirm useable energy in the shaped region.*

Experimental Setup

The output from a 520 nm CW single-mode fibre-coupled diode laser is magnified 40x, the central portion collimated, and a hard aperture positioned in front of the SQUIRCLE to create a 65 mm square high-order super-Gaussian input beam as shown below.

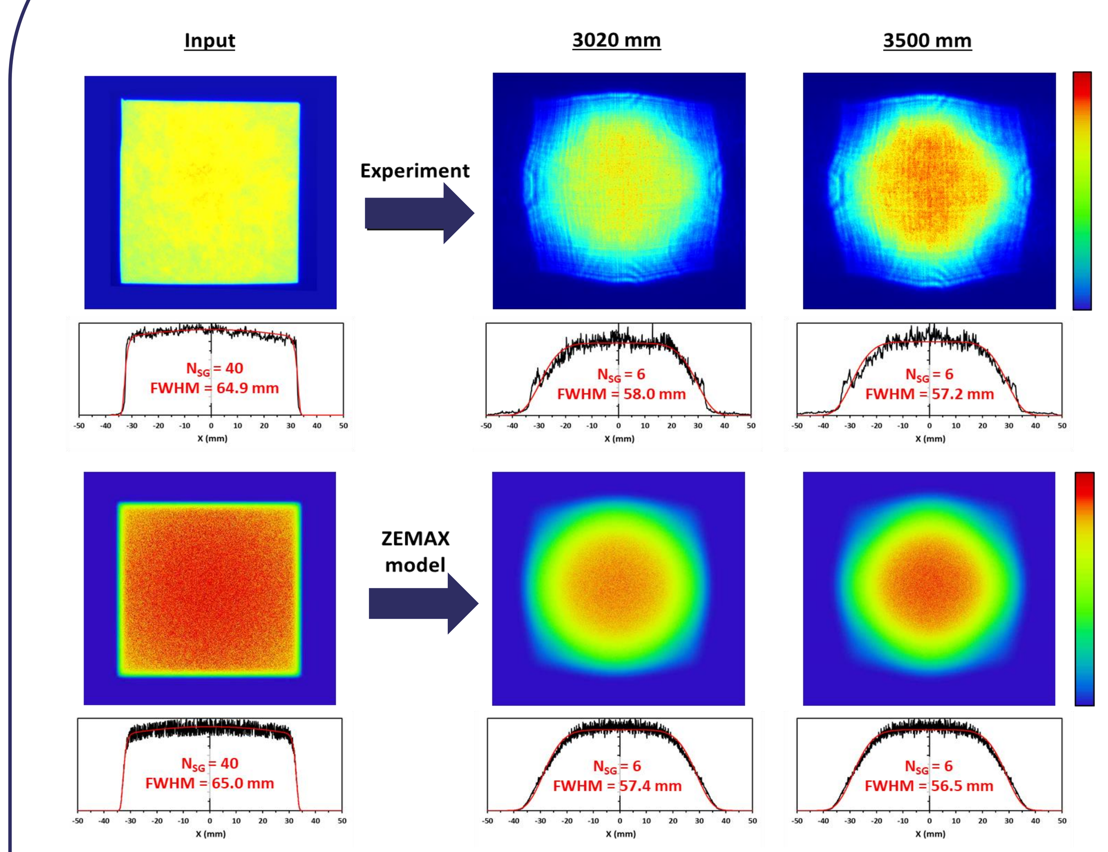


Beam profile before the SQUIRCLE



Main: CAD of the experimental setup for SQUIRCLE testing. A 520 nm CW Gaussian propagates through an expanding telescope and is collimated using a 2 m lens. The beam passes through a 65 mm square aperture before the SQUIRCLE and is then reshaped to a 55 mm circle at the image plane of a 3.5 m lens. **Top right:** schematic shows how beam profile images were taken with a ceramic screen at the image plane. **Bottom left:** simplified diagram illustrates how the SQUIRCLE will be used in the EPAC Ti:Sa Amplifier.

1. Beam Profile



Input is the collimated beam before the SQUIRCLE and the two outputs shown are just before and at the image plane of the 3.5m imaging lens. The input beam to the ZEMAX model has noise (~10%) artificially added to better represent the experimental beam. The model uses a GRID SAG surface to represent the SQUIRCLE and Physical Optics Propagation.

A 65 mm square collimated 40th order super-Gaussian is incident on the SQUIRCLE and is transformed into a 57 mm rounded 6th order super-Gaussian at the image plane.

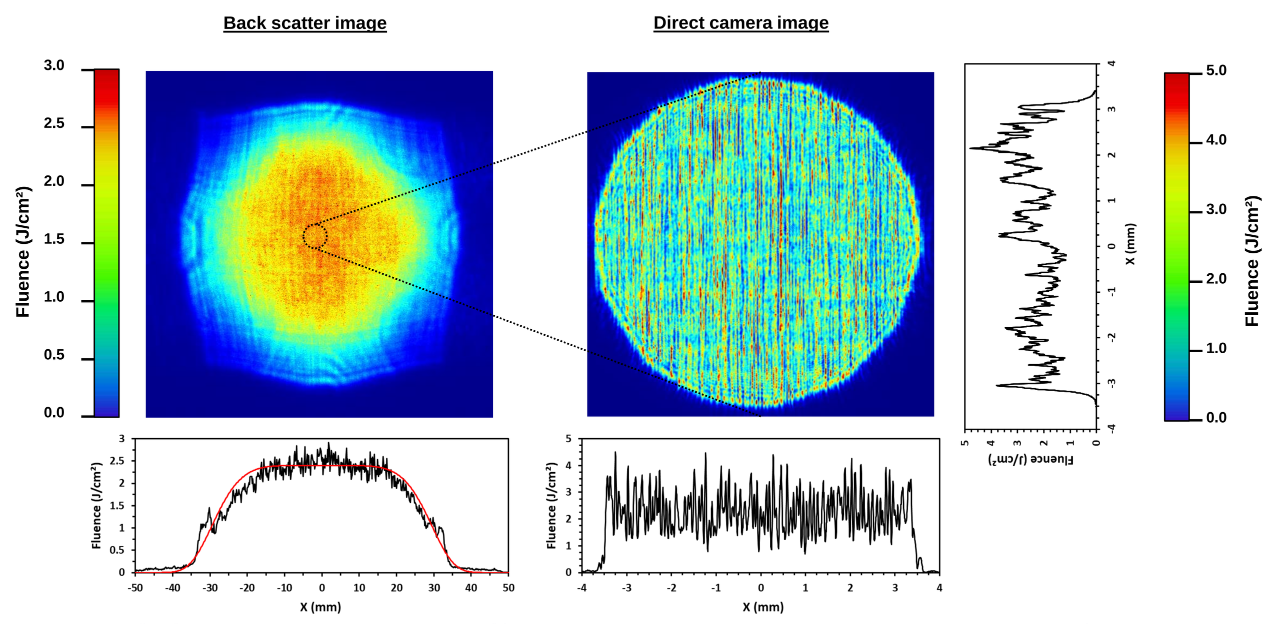
Due to space constraints, the beam was imaged on a ceramic Lambertian scatter screen at the image plane using a camera at near-normal incidence.

Overall the observed beam profile compares favourably to a ZEMAX model; however, several differences can be seen:

- Spatial modulations evident in the central part of the beam
- Diffraction edge effects on all four sides
- Observed beam has a slightly more pronounced diamond shape than the model predicts.

2. Uniformity & Fluence

The uniformity of the beam is important both to ensure uniform gain within the amplifier and to make sure peak fluence is below the LIDT of amplifier head optics. To confirm the magnitude of spatial modulations seen in back-scatter images, a camera was placed directly in the beam at the image plane allowing a small section of the beam to be examined in detail.



Left: figure shows the beam profile as imaged on a ceramic screen at the image plane. **Right:** figure shows a zoomed in view of the circled area, with both vertical and horizontal line-outs, measured using a AVT Manta G235 (1936 x 1216) camera, pixel size 5.86 µm. Fluence values for both profiles have been calibrated assuming a 40 J input beam.

Several observations can be made:

- Horizontal line-out: strong modulation with period of ~100 µm
- Vertical line-out: period of modulation reduced
- Difference in H & V modulation due to chosen 1D raster scan for prototype manufacture
- Current modulation level would result in peak fluence values of order 4.5 J/cm^2, assuming a 40 J input beam.

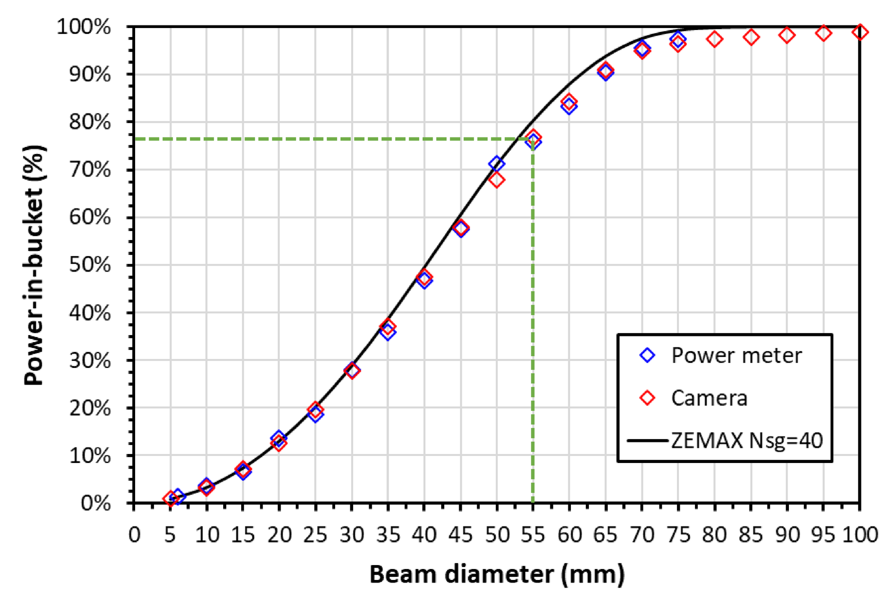
As shaped pump beams propagate at an angle to the amplified beams through the amplifier, spatial averaging through the depth of the amplifier is expected to minimise the impact of modulations on gain uniformity. Predicted fluence levels are close to damage threshold of dielectric dual-band AR coatings used on EPAC amplifier optics (fused silica pressure windows, Ti:Sa crystals). Optimisation of manufacturing process needed to reduce peak fluence levels.

3. Power in a Bucket

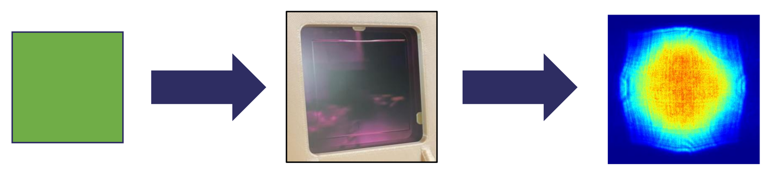
Two approaches have been used to measure the useable energy in the shaped region:

1. An iris is placed at the image plane of the reshaped beam, which is then focused onto a power meter. Transmission through the iris is then measured for varying iris aperture sizes
2. Integration of camera image collected at image plane.

Results are in good agreement with each other and predicted performance from ZEMAX model.



Percentage of input energy as a function of diameter after reshaping, with dashed line indicating the energy at the desired diameter.



The reshaped 55 mm beam contains **76% of the energy** of the 65 mm square beam incident on the SQUIRCLE.

Conclusions & Future Plans

	Input Beam Size (mm)	Input Beam Profile	Output Beam Size (mm)	Output Beam Profile	Power in the Bucket (%)
Specification	65	20th order super-Gaussian	55	12th order super-Gaussian	>90
Measured	64.9	40th order super-Gaussian	57.2	6th order super-Gaussian	76

Future work will include:

Re-design for a second SQUIRCLE:

PowerPhotonic will optimise design and manufacture a second SQUIRCLE prototype using lessons learnt from testing. Primary areas of focus are:

- Design: Modify design to improve edge steepness and super-Gaussian order to map more of the incident energy into the useable region of the reshaped beam
- Manufacture: Use 2D raster scan process for material removal and increase melting time to improve surface smoothness in order to reduce impact of intensity modulations.

Further testing:

- Investigate sensitivity to input beam size and profile shape. Modelling indicates that edge effects observed in reshaped beam occur as a result of mismatch between design and input beam characteristics
- Impact of laser linewidth on spatial modulation. Test SQUIRCLE using narrower linewidth input beam
- Investigate how the reshaped beam propagates to inform design of pump recycling scheme.